

ion funnel. This may be accomplished by providing a DC potential gradient across the adjacent elements of the ion funnel in addition to the RF voltages applied to the elements. For example, a resistor chain may be used to effect a gradual change in the DC electric field across the individual elements. Each element thus has a time varying voltage corresponding to the summation of the applied DC and RF potentials. The simultaneous constraining force supplied by the RF currents and driving force supplied by the DC gradient thus acts to drive charged particles through the ion funnel.

Alternatively, or in combination with the DC field, mechanical means may be employed for driving the charged particles through the funnel. For example, methods based on gas dynamics may be applied. In this case a gas flow pressure gradient or partial vacuum at the exit of the ion funnel may be employed to push or draw charged particles through the funnel. Also, a fan may also be employed to blow charged particles into the entry and through the funnel.

The specific configuration of the ion funnel may be easily altered to suit a desired need. For example, in applications for atmospheric monitoring for ambient charged particles, the entry may be made as large as desired, since the frequency and RF voltages necessary for effective operation depend primarily upon the elements thickness and the spacing of the elements, but not the acceptance area. Also, the ion funnel may be configured to trap or direct particles with specific mass to charge ( $m/z$ ) ratios. For example, all else held constant, thinner elements would trap or direct higher  $m/z$  ions or charged particles while thicker elements would trap lower  $m/z$  ions or charged particles. Similarly, all else held constant, the use of higher RF frequencies would tend to trap or direct charged particles or ions having smaller  $m/z$  ratios. Likewise, all else held constant, the use of larger voltages would tend to trap or direct charged particles or ions having larger  $m/z$  ratios. Finally, as described above, the shape of the cross section of the resultant charged particle beam may be controlled by changing the shape of the elements or the apertures in the elements.

It should be noted that the ion funnel herein described may be utilized in a wide variety of settings where it is desired to focus a dispersion of charged particles. For example, the ion funnel utilized in mass spectrometers, such as for combined on-line capillary electrophoresis mass spectrometry, would allow much improved focusing of the ion current and thus greatly enhanced analytical sensitivity. In a typical mass spectrometer, the ion current is directed through a series of chambers which are subjected to pumping to reduce pressure to a level amenable with mass spectrometric analysis. The chambers are thus separated by apertures designed to limit gas flow and allow a transition form a region at higher pressure to a region at lower pressure. By positioning the ion funnel adjacent to an ion source at atmospheric pressure, the ion beam may be maintained at near atmospheric pressure, and the incoming ion current is effectively focused into the device, minimizing ion dispersal and thus analyte signal losses. Similarly, in applications where diffuse ion beams are generated by methods such as electrospray, thermospray, and discharge ionization, the ion funnel allows greater ion current, and due to the focusing effect on the ions and resultant decrease in ion dispersion, greater ability to aim or focus the ion beam at a desired target, collection device or detector. Used in conjunction with photo-ionization sources, much greater ion collection efficiency and sensitivity can be obtained since the ionization volume can be made arbitrarily large. Also, the ion funnel may be used to trap charged particles by

applying a DC potential to the exit of the ion funnel sufficient to preclude the escape of the charged particles of interest. The ion population could therefore be increased in the ion funnel "trap" to a high level, and the DC potential could be lowered at any time to release the trapped ions in a pulse for introduction to another region. Coordinating the release of the pulse of ions with the opening of mechanical shutter or gate used to block an aperture separating two regions maintained at different pressures by differential pumping, thus allowing significant advantages. For example, because it is only necessary to open the gate or shutter at the precise moment of the release of the trapped ions, a great reduction in the gas load on the pumping system can be achieved. This allows high sensitivity for instruments using only small vacuum pumps. The foregoing is only a single example of a possible use of the ion funnel's capability to trap ions and release ions in a pulsed fashion. Other uses and advantages of trapping ions and releasing ions in a pulsed fashion will be apparent to those skilled in the art, and the use of the present invention should in no way be limited to the example of releasing ions in a pulsed fashion in conjunction with a shutter or gate used to block an aperture separating two regions maintained at different pressures by differential pumping.

The ion funnel also allows the capture of free ions in gaseous atmospheres where no particular ion source is apparent. For example, by forcing air through an ion funnel, ions of interest may be effectively directed towards a detector for atmospheric analysis. As demonstrated by the foregoing, and as will be apparent to those skilled in the art, the ion funnel is useful across a broad range of activities and in a broad range of devices where it is desirable to focus dispersed ions. The present invention should in no way be limited to its incorporation in any particular application, device or embodiment.

When charged particles are driven into the entry and then through the plurality of apertures which make up the ion funnel, the effect of the combined forces and fields is to direct the charged particles through the exit of the ion funnel. In this manner, a dispersion of charged particles is compressed as they pass through the ion funnel, and the charged particles are focused from a dispersion into a compact beam. The charged particles may be driven by either mechanical means, for example a fan, a vacuum, or both, or electrical means, for example by providing a dc potential gradient down the central axis of the ion funnel by providing increasing DC voltages to each of the elements. The final aperture can also be used to define the passage into a region of lower pressure, as in a mass spectrometer vacuum system incorporating multiple regions of differential pumping. Alternatively, the final element may be positioned immediately adjacent to such an aperture. In either case concerns about focusing, space charge, differential pumping, and possible electrical discharges, familiar art to those who work in this field, must be considered in the design of any specific implementation. It must also be recognized that it is possible to use multiple ion funnels in series. One case where this is particularly attractive is in regions of different pressure so that ions can be effectively transferred through multiple aperture with minimal losses. It should also be recognized that the optimum RF and DC electric fields may be significantly different for such multiple funnel devices; one reason for this would be differences in pressure that would alter the effect of the gas collisions.

In a preferred embodiment of the present invention, a multipole lens element, (i.e. quadrupole, hexapole, octapole), but preferably a short 0.5–5 cm quadrupole lens